

United States Patent [19]

Kunzler et al.

[11] Patent Number: **5,006,622**

[45] Date of Patent: **Apr. 9, 1991**

[54] **POLYMER COMPOSITIONS FOR CONTACT LENSES**

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[21] Appl. No.: **34,292**

[22] Filed: **Apr. 2, 1987**

[51] Int. Cl.⁵ **C08F 32/00**

[52] U.S. Cl. **526/309; 526/304; 560/220; 564/204; 351/160 H**

[58] Field of Search **526/304, 309; 560/220; 564/204; 351/160 H**

[56] **References Cited**

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3,679,504 7/1972 Wichterle 156/62
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[57] **ABSTRACT**

Branched alkylhydroxycycloalkyl methacrylate monomers, such as t-butylhydroxycyclohexyl methacrylate, are polymerized with hydrophilic monomers and cross-linking agents to produce compositions for shaped biomedical devices, including soft contact lenses. Such copolymers have high oxygen permeability and good mechanical properties.

3 Claims, No Drawings

POLYMER COMPOSITIONS FOR CONTACT LENSES

BACKGROUND OF THE INVENTION

This invention relates to polymeric compositions formed by reacting a hydrophilic monomer, a hydrophobic strengthening agent monomer, a crosslinking agent monomer and a polymerization initiator. The novel hydrophobic strengthening agent monomer provides increased strength without decreasing the oxygen permeability of the polymer material.

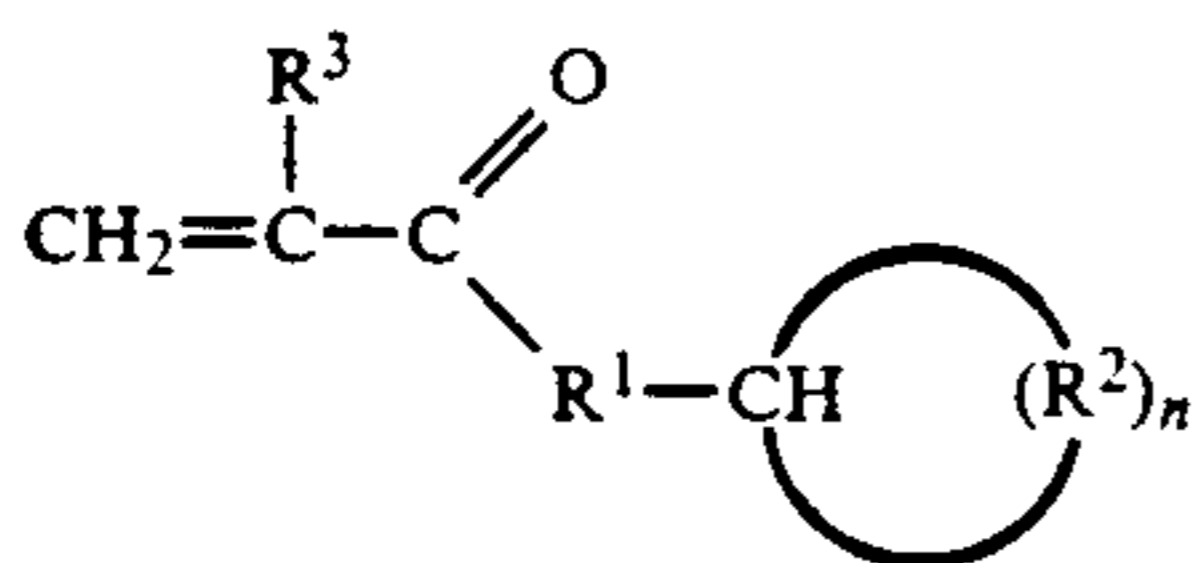
Soft contact lens materials are made by polymerizing and crosslinking hydrophilic monomers such as 2-hydroxyethylmethacrylate, N-vinyl-2-pyrrolidone, and combinations thereof. The polymers produced by polymerizing these hydrophilic monomers exhibit significant hydrophilic character themselves, and are capable of absorbing a significant amount of water in their polymeric matrices. Due to their ability to absorb water, these polymers are often referred to as "hydrogels". These hydrogels are optically clear and, due to their high levels of water of hydration, are particularly useful materials for making soft contact lenses. However, the high levels of water of hydration of hydrogels contributes to their relative lack of physical strength which results in hydrogel contact lenses being relatively easy to tear.

Various hydrophobic monomers have been copolymerized with these hydrophilic monomers in order to obtain polymers with improved physical strength. Such hydrophobic monomers include styrene, and various acrylates and methacrylates such as methylmethacrylate, isobornylmethacrylate, and t-butylcyclohexylmethacrylate.

For instance, Chromecek teaches that t-butylcyclohexylmethacrylate is a particularly useful monomer when copolymerized with 2-hydroxyethylmethacrylate in U.S. Pat. No. 4,436,887. However, while these state of the art hydrophobic monomers do increase the physical strength of hydrogel polymers, they also produce polymers with lower levels of water of hydration than unmodified hydrogels. It is an object of the present invention to provide polymeric materials with increased physical strength and high levels of water of hydration.

SUMMARY OF THE INVENTION

According to the present invention it has been found that certain hydrophobic monomers act as strengthening agents when copolymerized with hydrophilic monomers such as 2-hydroxyethylmethacrylate, N-vinyl-2-pyrrolidone and the like. These hydrophobic strengthening agent monomers are represented by the general formula



wherein:

R³ is H or CH₃;

R² is a divalent alkylene radical chosen from the group consisting of —CH₂—, —CHOH—, and —CHR⁴ where R⁴ denotes a branched alkyl group with

3 to 8 carbon atoms and preferably with 4 to 6 carbon atoms; and

R¹ denotes O or NH; the R² radicals are chosen so that at least one —CHOH— radical is present, at least one —CHR⁴— radical is present and is separated from the —CHOH radical by at least one —CH₂— radical; and n is 4, 5, 6, or 7.

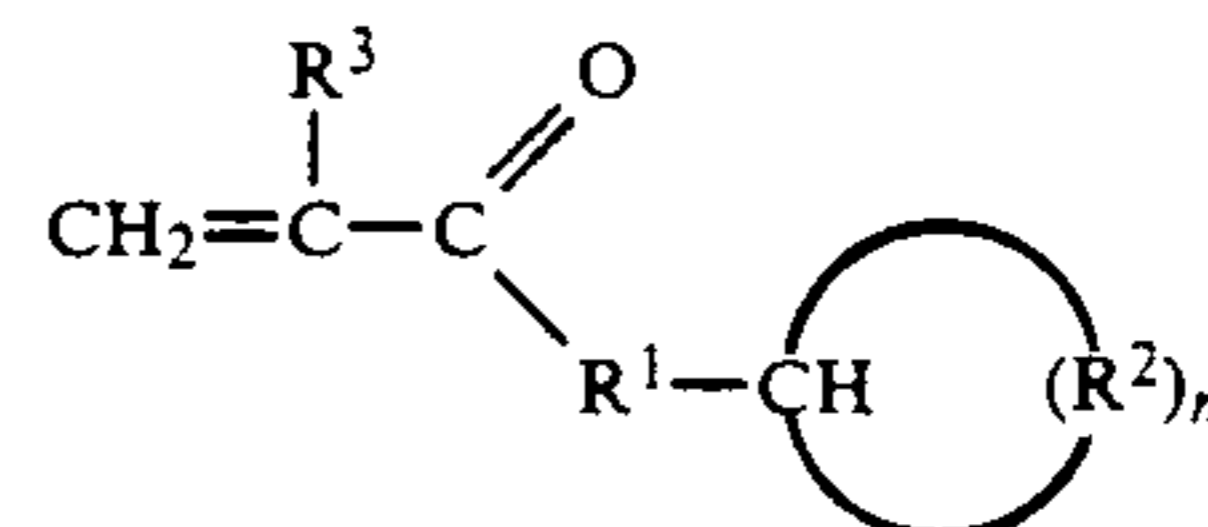
Copolymers of the present invention's hydrophobic monomers with hydrophilic monomers used in the production of hydrogel materials exhibit substantial hydrophilic character, and substantially greater mechanical strength than state of the art hydrogel materials.

DETAILED DESCRIPTION OF THE INVENTION

The present invention relates to hydrophobic monomers which can be copolymerized with hydrophilic monomers used in making soft contact lenses in order to provide polymeric materials with improved strength. These materials may also contain crosslinking agents and polymerization initiators. Thus, the present invention also relates to the product of polymerizing hydrophilic monomers with hydrophobic monomer strengthening agents and, optimally, crosslinking agents and polymerization initiators.

By weight the hydrophilic monomers comprise from 35 to 90 weight percent of a mixture useful in forming soft contact lenses. The novel hydrophobic strengthening agents comprise from 10 to 65 weight percent, the crosslinking agent comprises from 0 to 5 weight percent and the polymerization initiator comprises from 0 to 5 weight percent of the mixture to be polymerized.

The novel hydrophobic strengthening agent monomers of the present invention useful in soft contact lens compositions are represented by the general formula



wherein:

R¹ is O or NH;

R² is chosen from the group of radicals consisting of —CH₂—, —CHOH—, and —CHR⁴— where R⁴ denotes a branched alkyl radical with 3 to 8 carbon atoms and preferably 4 to 6 carbon atoms;

R³ is H or CH₃; and

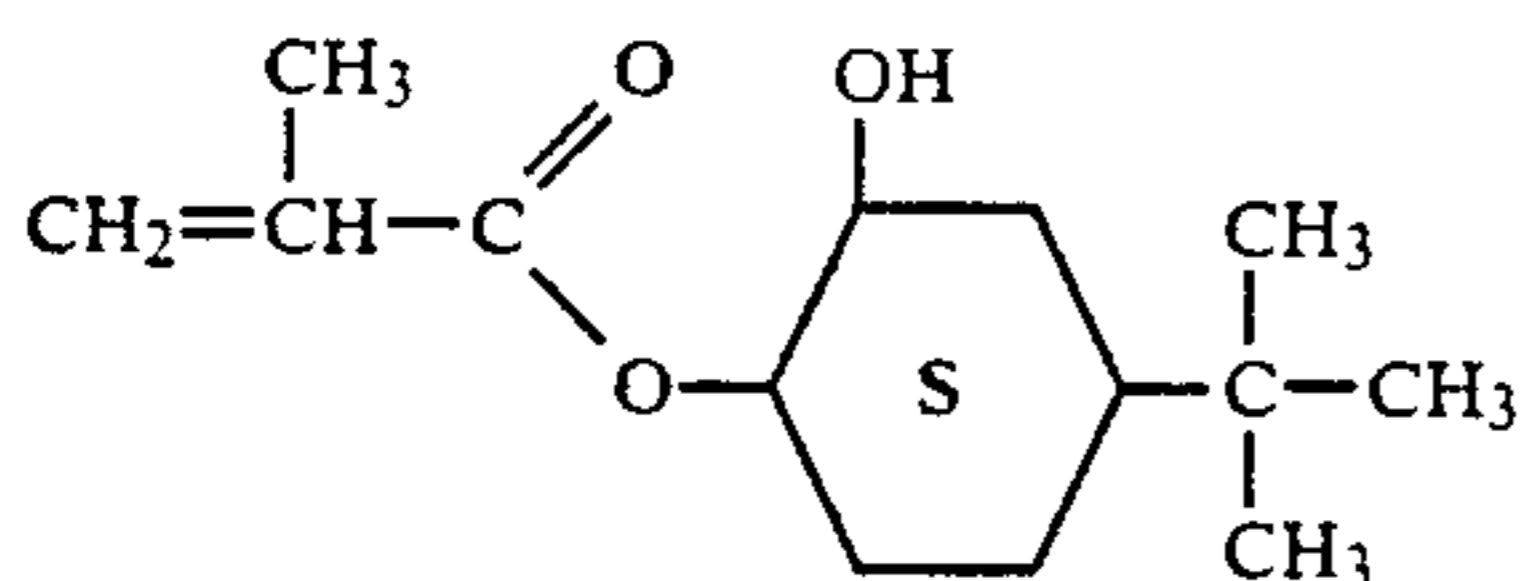
n is 4, 5, 6 or 7.

At least one R² radical is —CHOH— and at least one R² radical is —CHR— and these two radicals are separated by at least one —CH₂— radical.

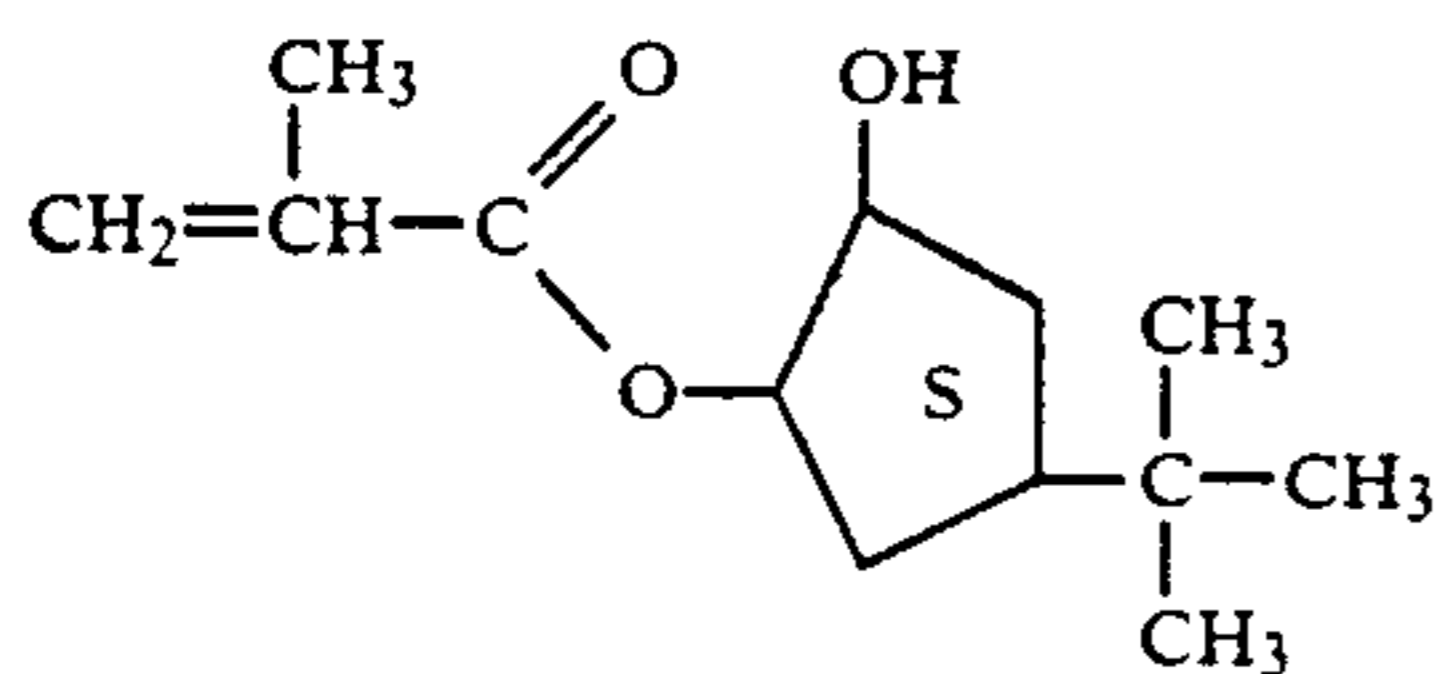
These branched alkyl hydroxy cycloalkyl acrylates, or the corresponding methacrylates, acrylamides and methacrylamides are effective strengthening agents in soft contact lens polymeric compositions. The resulting polymers are optically clear and possess a combination of high levels of water of hydration and good mechanical properties.

Non-limiting examples of the hydrophobic strengthening agent monomers of the present invention include:

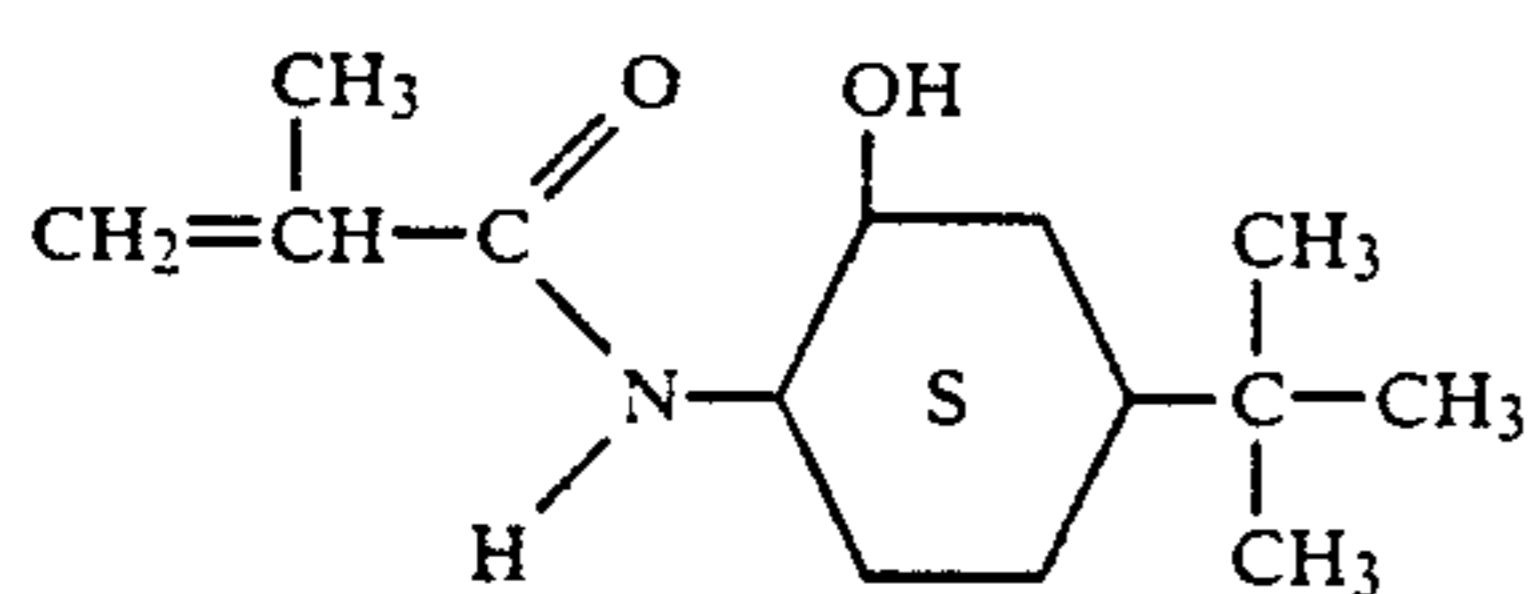
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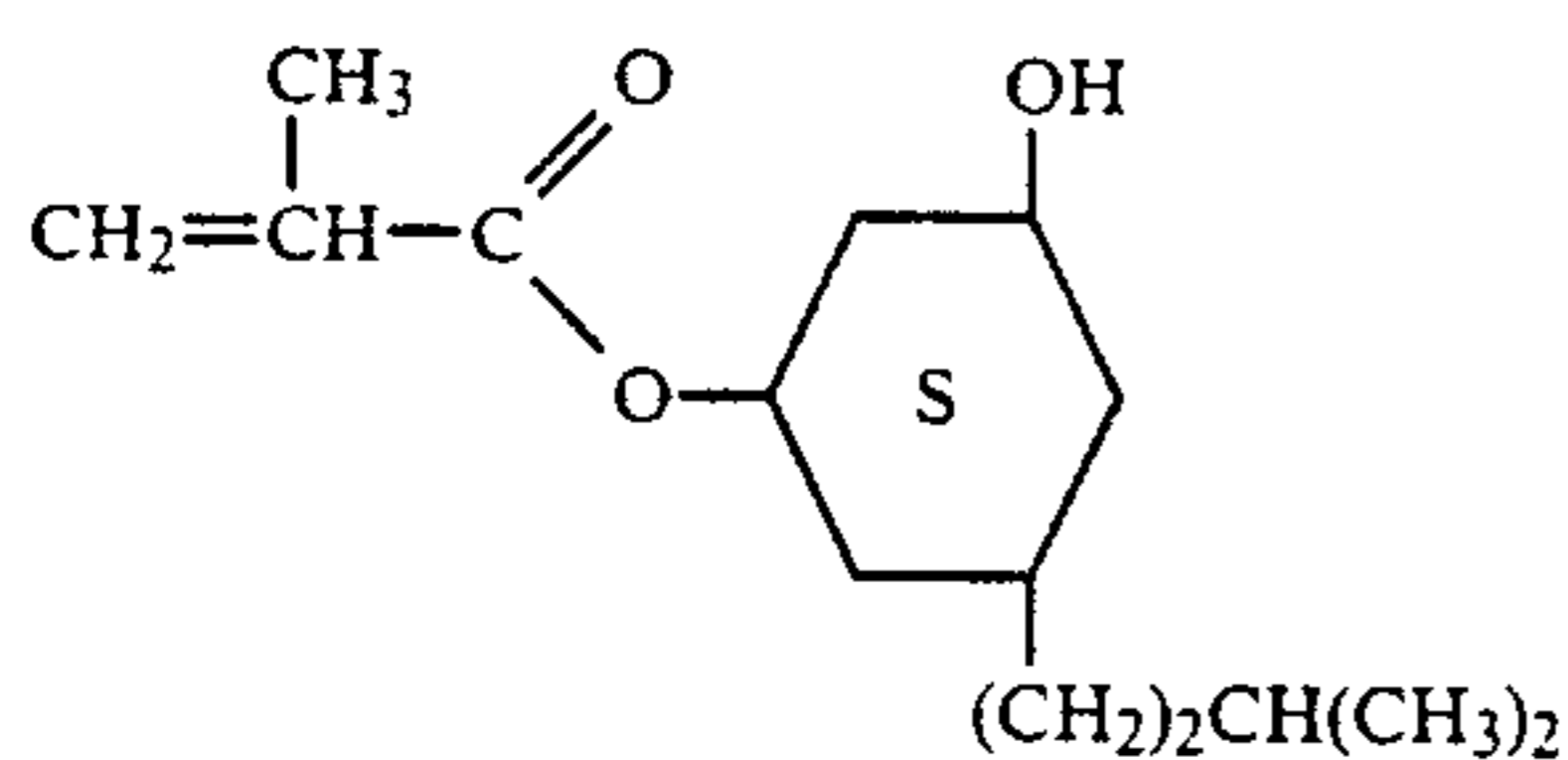
(4-t-butyl, 2-hydroxycyclohexyl methacrylate (TBE));



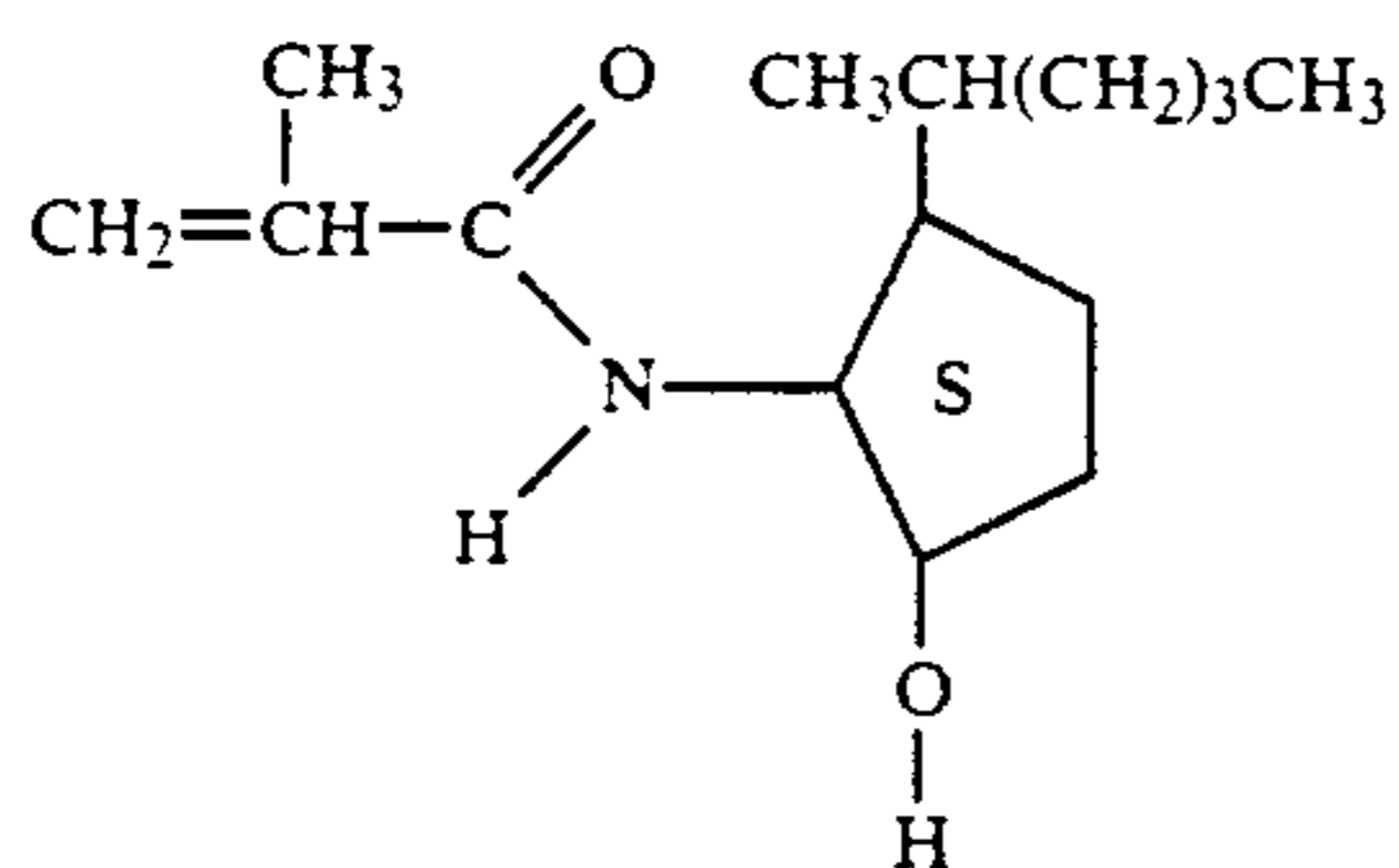
(4-t-butyl, 2-hydroxycyclopentyl methacrylate);



(methacryloylamino-4-t-butyl-2-hydroxycyclohexane);

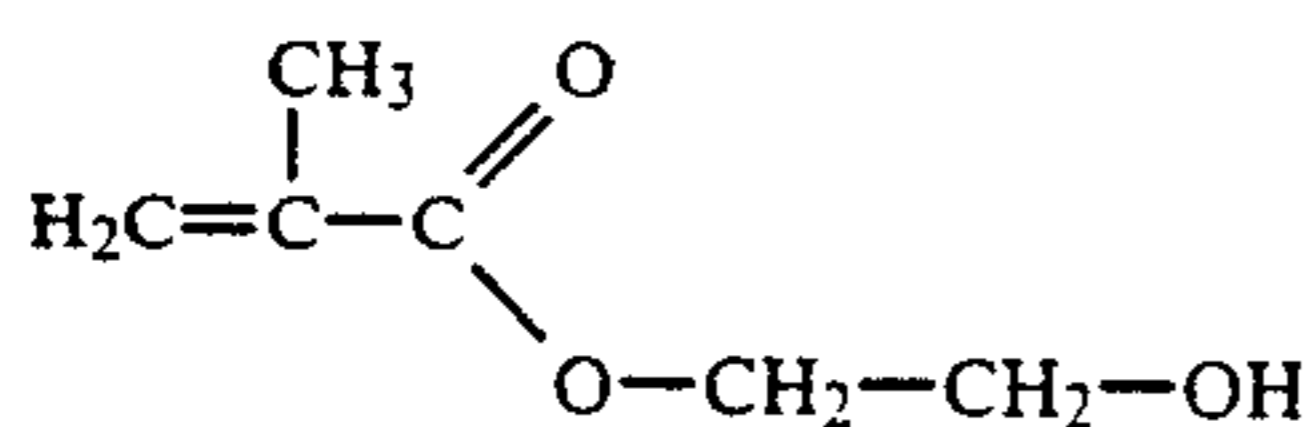


(6-isopentyl,3-hydroxycyclohexyl methacrylate);

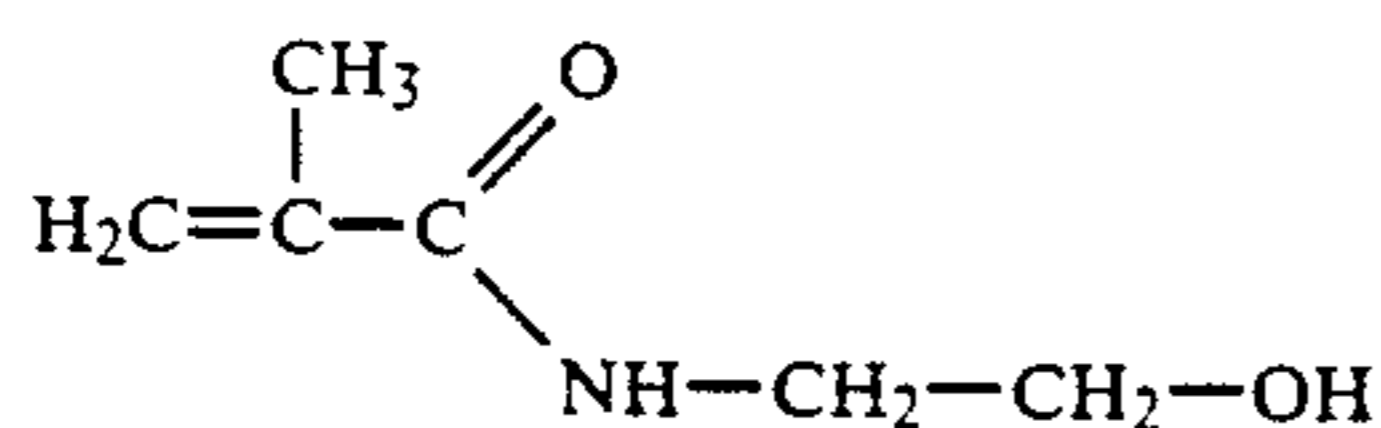


(methacryloylamino, 2-isohexyl, 5-hydroxy cyclopentane);

The hydrophilic monomers useful in the present invention are those known in the art to be useful in making soft contact lenses. The following are non-limiting examples of hydrophilic monomers useful in contact lens formulations of this invention:



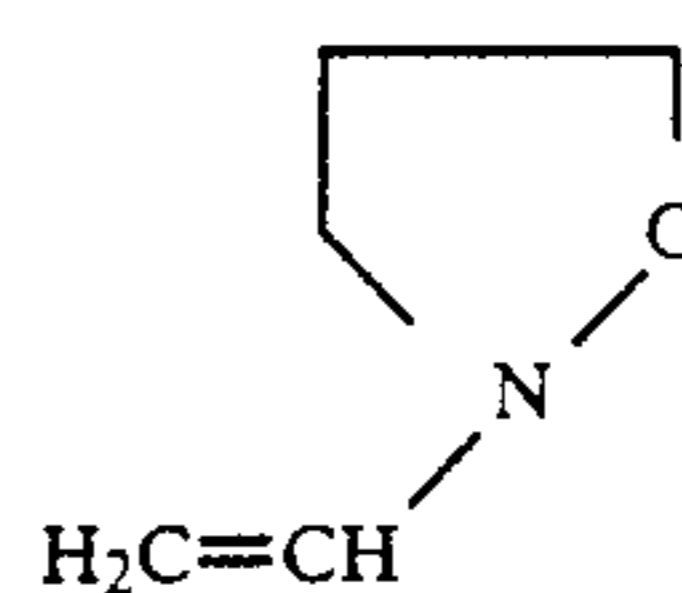
(2-hydroxyethyl methacrylate (HEMA));



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(N-(2-hydroxy ethyl)-methacrylamide);

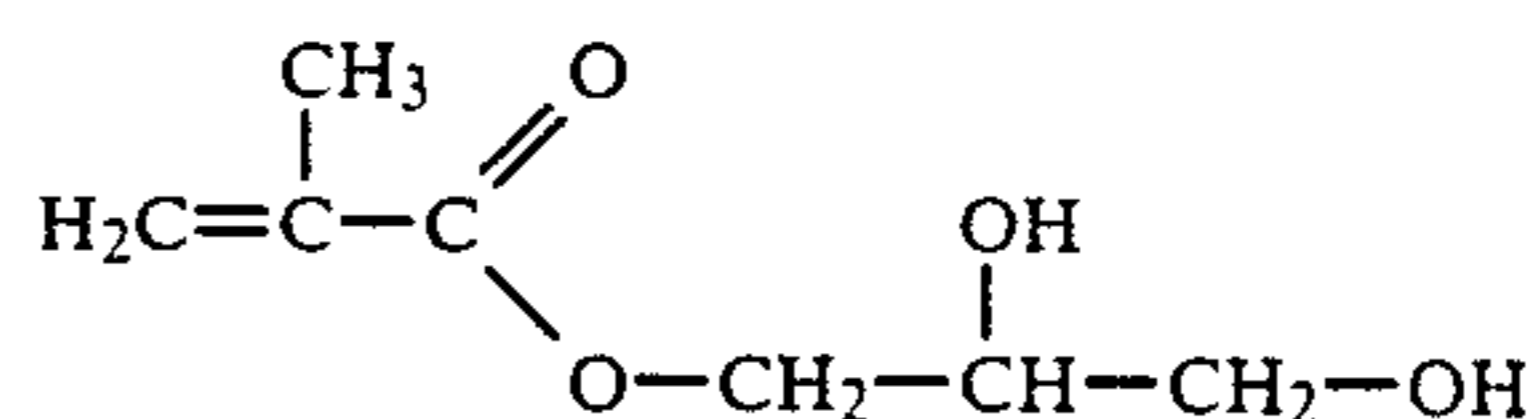
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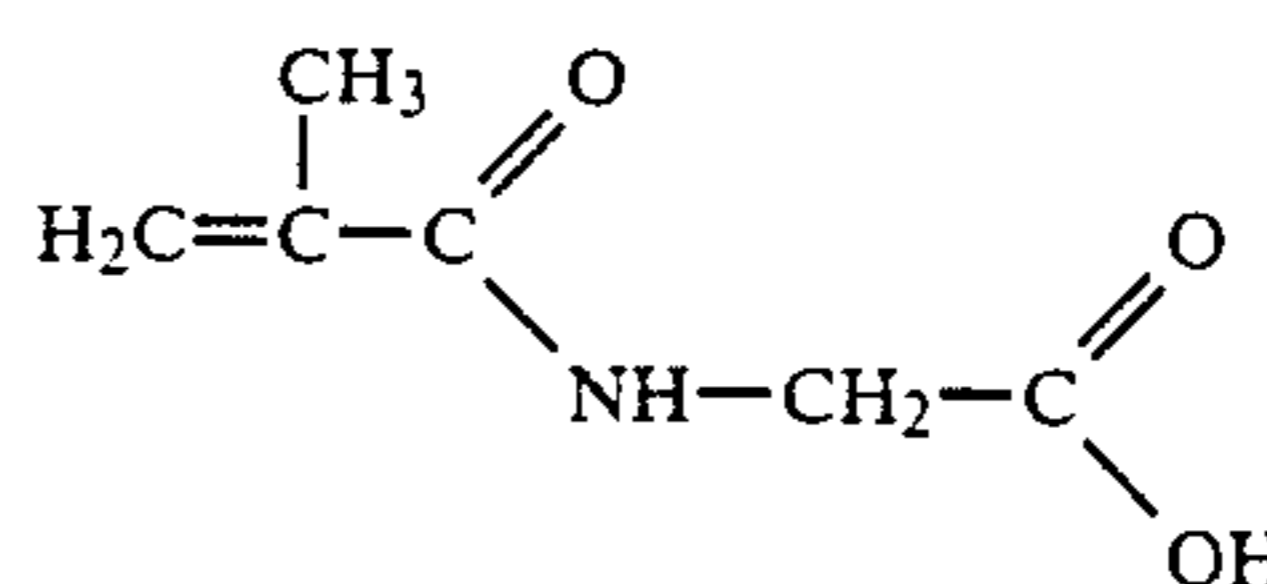
(N-vinyl-2-pyrrolidone (NVP));

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(glyceryl methacrylate (GM));

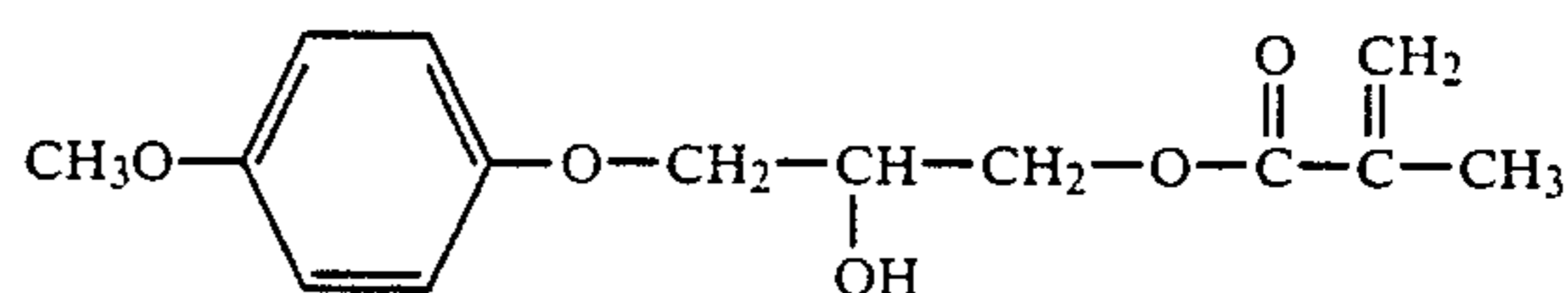
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(N-methacryloyl glycine (MG));

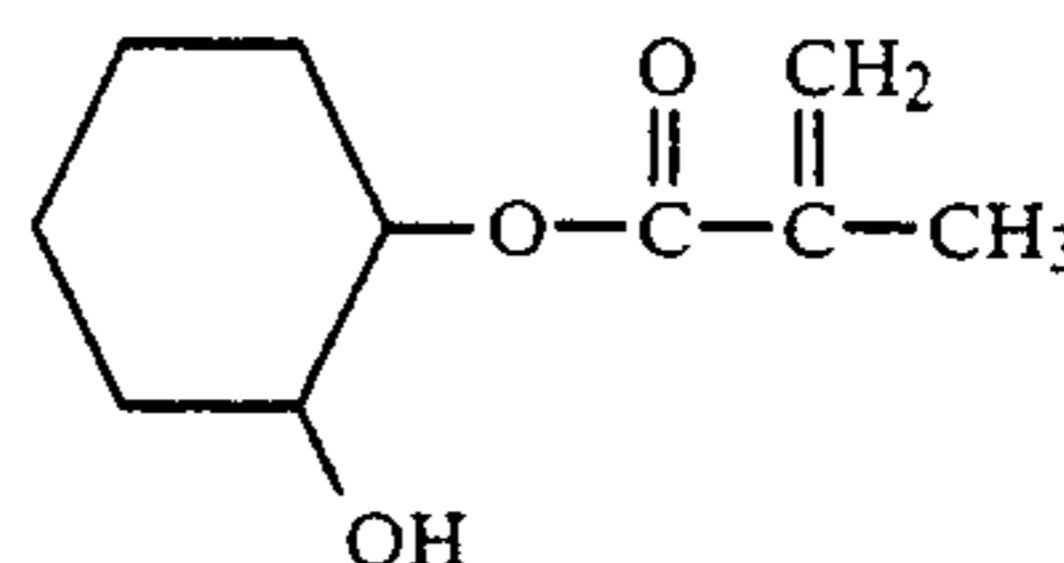
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(2-hydroxy-3-methacryl(propyl)-4-methoxy phenylether);

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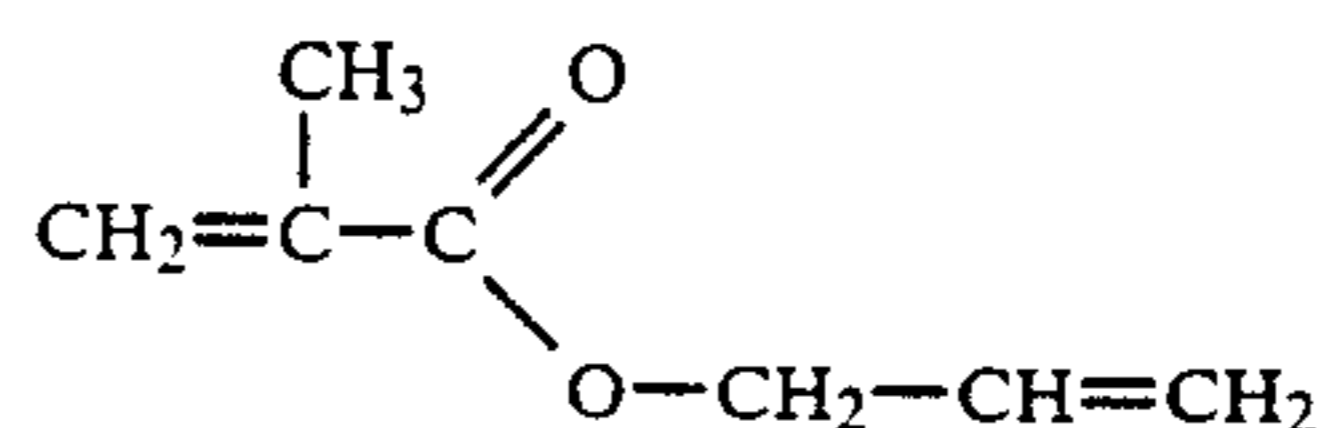


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(2-hydroxy cyclohexylmethacrylate).

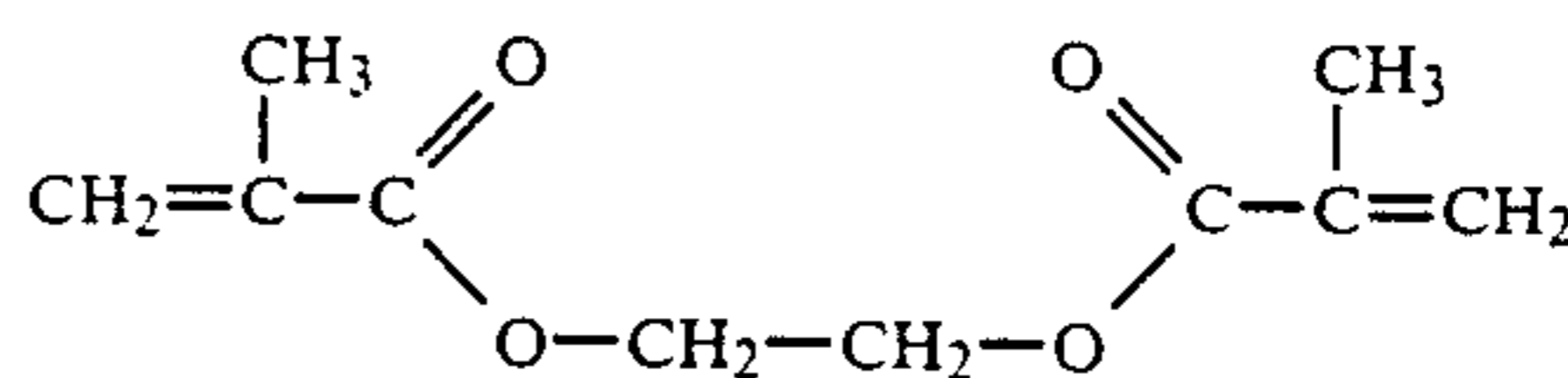
The crosslinking agents which are useful in the present invention are those crosslinkers known in the art to be useful in making soft contact lenses. The following are non-limiting examples of crosslinking agents useful in contact lens formulations of this invention:

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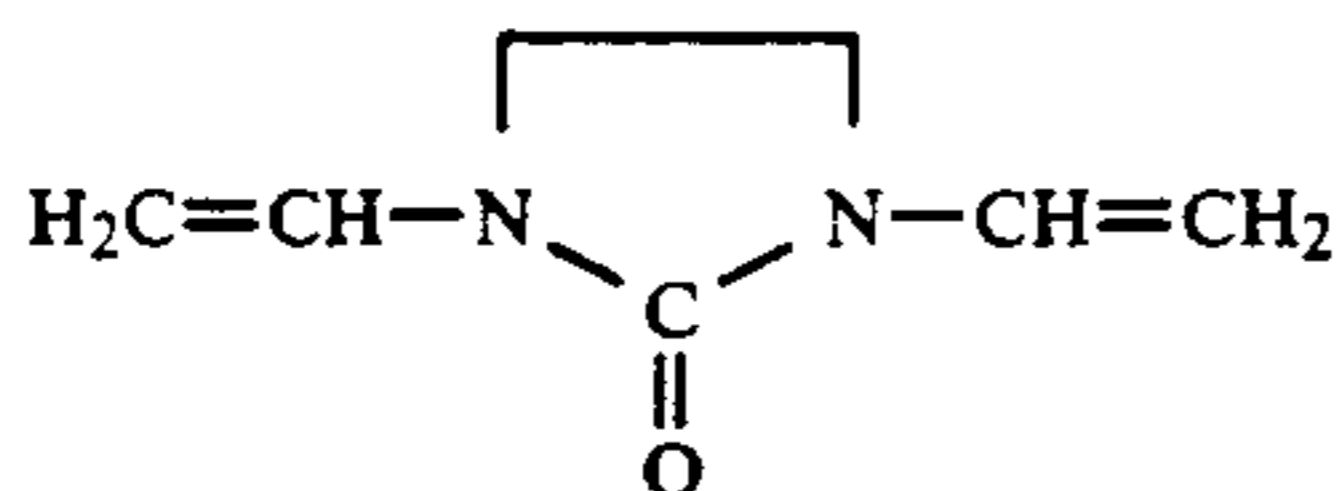


(allyl methacrylate);

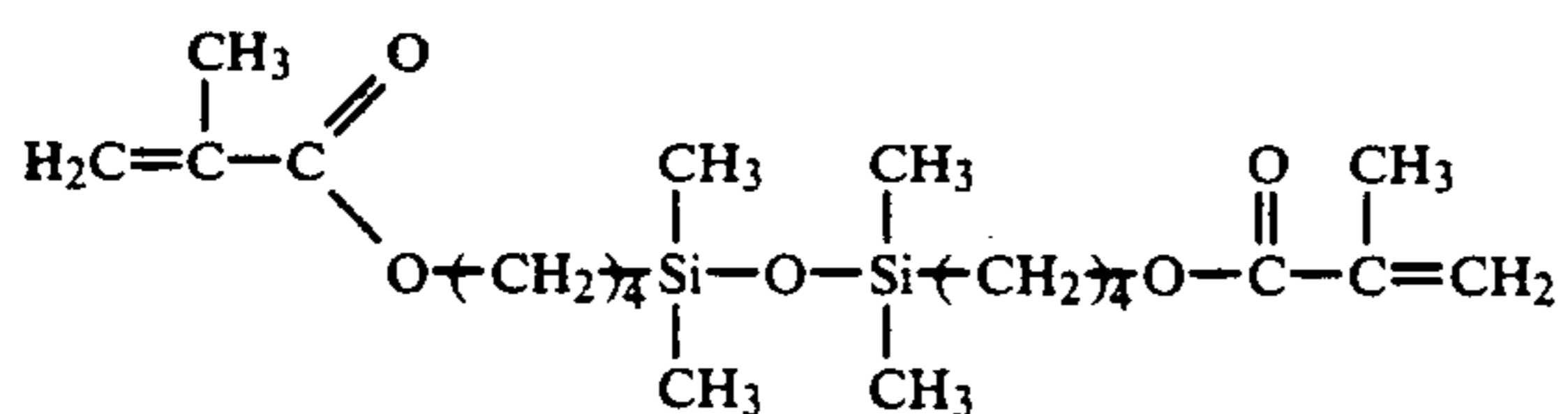
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(ethylene glycol dimethacrylate (EGDMA));



(divinyl ethylene urea (DVEU)); and



(1,3-bis (4 methacryloxybutyl) tetramethyl disiloxane).

Various mixtures of hydrophilic monomers, hydrophobic strengthening agent monomers, and optionally crosslinking agents can be used to produce polymeric materials useful in contact lenses. The following table provides several examples of such useful mixtures. The table does not exhaust the list of examples which are within the scope of the invention.

TABLE I

Hydrophilic Monomer(s)	Strengthening Agent Monomer(s)	Crosslinking Monomer(s)
hydroxyethylmethacrylate (HEMA)	4-t-butyl-2-hydroxy-cyclohexyl-methacrylate (TBE)	ethyleneglycol dimethacrylate (EGDMA)
HEMA	4-t-butyl-2-hydroxy-cyclohexyl-methacrylamide (TBA)	EGDMA
HEMA	octafluoropentyl methacrylate (OFPMA)/TBE	EGDMA
HEMA/N-methacryloyl glycine	TBA	EGDMA
N-vinyl 2-pyrrolidone (NVP)	TBE	DVEU
NVP	TBE	DVEU/EGDMA
NVP	TBE	Allyl methacrylate
Glyceryl methacrylate (GM)	TBE	EGDMA
HEMA/GM	TBE	EGDMA
NVP	OFPMA/TBE	DVEU

The most preferred contact lenses of the instant invention have an oxygen transport rate of at least about $2 \times 10^{-6} \text{cm}^3/(\text{sec. cm}^2 \text{ atm.})$, are hydrolytically stable, biologically inert, transparent, resilient, and have a softness preferably of about 60 or below on the Shore hardness A scale when hydrated. The more preferred materials have a Shore hardness between 25 to 35 on the A scale. The tensile modulus of elasticity of these hydrated polymers is at least about 50 g/mm^2 , preferably from about 75 g/mm^2 to about 100 g/mm^2 and the tear strength is at least about 2.0 g/mm thickness, preferably from about 2.0 g/mm to about 250 g/mm thickness. High tensile modulus of elasticity is desirable for strength and durability. High tear strength is desirable in order to prevent damage to the contact lens (1) due to tearing during patient use, i.e., the removing and the placing of the lens in the eye, and (2) to prevent damage to the lens during cleansing and disinfecting.

Soft contact lenses, made from the polymers of the instant invention, can be made large enough to cover the entire cornea of the eye, resulting in more comfort

because of their good oxygen permeability. Conventional hard contact lenses have to be made smaller due to their poor oxygen transportability. Furthermore, the larger the lenses, the easier it is to locate the optical center of the lenses. The larger the lens the easier it is to maintain the optical axis which is required in making special lenses for people with astigmatism. Another advantage of the preferred soft lenses of the instant invention is the instant preferred soft lenses have a softness similar to HEMA lenses but are more oxygen permeable. HEMA lenses are not oxygen permeable or capable of transporting oxygen to a degree necessary to meet all the requirements of the human cornea, especially for extended wear applications.

While the polymers of the instant invention can be used to prepare contact lenses, these polymers can also be used to make other shaped articles for use in biomedical applications. These polymers can be used to make biomedical devices such as dialyzer diaphragms used in artificial kidneys and other biomedical implants, such as disclosed in Wichterle, U.S. Pat. No. 2,976,576 and Wichterle U.S. Pat. No. 3,220,960. The instant polymers can be used in preparing therapeutic bandages as disclosed in Shephard, U.S. Pat. No. 3,438,043. The instant

polymers can also be used in preparing such medical surgical devices as heart valves, vessel substitutes, intra-uterine devices, membranes, films, dialyzer diaphragms, catheters, mouth guards, denture liners and other such devices as disclosed in Shephard U.S. Pat. No. 3,520,949 and Shephard U.S. Pat. No. 3,618,231. The instant polymers can be used to modify collagen to make blood vessels, urinary bladders and other such devices as disclosed in Kliment U.S. Pat. No. 3,563,925. The instant polymers can be used to make catheters as disclosed in Shephard U.S. Pat. No. 3,566,874. The polymers can be used in semipermeable sheets for dialysis, artificial dentures and all of such disclosures as set forth in Stoy U.S. Pat. No. 3,607,848. The instant polymers can be used in ophthalmic prostheses and all other uses disclosed in Wichterle U.S. Pat. No. 3,679,504.

The shaped articles for use in biomedical applications made from the polymers of this invention have physiochemical properties rendering them suitable for prolonged contact with living tissue, blood or the mucous

membrane such as surgical implants, blood dialysis devices, blood vessels, artificial ureters, artificial breast tissue and membranes intended to come in contact with body fluids outside of the body, for example, membranes for kidney dialysis and heart/lung machines, and the like. For example, it is known that blood is rapidly damaged in contact with artificial surfaces. The design of a synthetic surface which is antithrombogenic and nonhemolytic is necessary for prosthesis and devices which contact blood. The polymers of the present invention provide such surfaces.

The polymers disclosed herein can be boiled and/or autoclaved in water without being damaged, whereby sterilization may be achieved. Thus, an article formed from the instant polymers disclosed herein may be used in surgery where an article compatible with living tissue or with the mucous membrane is required.

The polymers disclosed herein can be used in shaped articles in hydrated states and can contain high amounts of water of hydration.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The utility of the compositions of this invention as soft contact lens formulations is illustrated in the following examples Examples 1, 3, 6, 7, 8 (in part), and 9 illustrate the use of 4-t-butyl-2-hydroxycyclohexyl methacrylate (TBE), a preferred strengthening agent of this invention. Example 2 illustrates the use of 4-t-butyl-2-hydroxy cyclohexyl methacrylamide, which is another preferred strengthening agent of this invention. For comparative purposes, examples 4, 5, 8 (in part) and 10 illustrate the use of t-butylcyclohexyl methacrylate, which is a state of the art strengthening agent outside the scope of this invention, and which differs from the strengthening agent of the invention only in the absence of a hydroxy group on the cyclohexyl substituent of the monomer.

EXAMPLE 1

A mixture was made containing 77.0 g of glyceryl methacrylate, 22.5 g of 4-t-butyl-2-hydroxycyclohexyl methacrylate, and 0.5 g of ethyleneglycol dimethacrylate. To this mixture was added 0.5 g of benzoin methyl ether, an ultra violet induced polymerization initiator. The solution was cast between glass plates separated by a Teflon (DuPont registered trademark) perfluoro polymer gasket 0.3 mm thick and cured. After curing, the film was released from the glass plates and hydrated and extracted in hot distilled water for 4 hours.

Next the film was placed in a borate buffered saline solution for testing. The resultant material was optically clear and had a water content of 53% and an oxygen permeability of 18.0×10^{-11} cm³ cm/(sec. cm² mmHg). The mechanical properties were measured according to the following test methods and gave the following results:

PROPERTIES (RESULT)	TEST METHOD
Young's modulus of elasticity (60 g/mm ²)	ASTM-D 1708
Tensile strength (84 g/mm ²)	ASTM-D 1708
% Elongation (164%)	ASTM-D 1708
Tear Initiation (3.8 g/mm)	ASTM-D 1938

EXAMPLE 2

A mixture of 83.5 parts by weight of 2-hydroxyethyl methacrylate, 10 parts of 4-t-butyl-2-hydroxycyclohexyl

methacrylamide, 6 parts of n-methacryloylglycine, and 0.5 parts of ethylene glycol dimethacrylate was made. To this mixture was added 0.17 parts by weight of benzoin methyl ether, a U.V. initiator, and 10 parts by weight of ethylene glycol as a diluent. The mixture was placed between glass plates and cured as described in Example 1. The resultant polymer when hydrated had a water content of 65% and an oxygen permeability of 33×10^{-11} cm³ cm/(sec. cm² mmHg). The mechanical properties measured were the following:

PROPERTY	MEASURED VALUE
Young's modulus of elasticity	44 g/mm ²
Tensile Strength	34 g/mm ²
% Elongation	139
Tear Initiation	2.0 g/mm

EXAMPLE 3

A mixture was prepared using 89.9 parts of n-vinyl-2-pyrrolidinone, 10 parts of 4-t-butyl-2-hydroxycyclohexyl methacrylate, 0.1 parts of divinyl ethylene urea and 1 part of 2,2-azobis(isobutyronitrile) and 0.1 part of 2,2-azobis(2,4-dimethyl-4-methoxyvaleronitrile). The solution was purged with nitrogen for 10 minutes and then poured into polypropylene tubes having a diameter of 18 mm and a length of 300 mm. The tubes were closed then immersed in a constant temperature bath and heated to 32° C. for 72 hours, then raised to 45° C. and held for 48 hours, and then raised to and held at 60° C. for 48 hours. The resultant rod was removed from the water bath and placed in an oven at 90° C. for 2 hours for post curing. Cylinders were cut from the rod and annealed by heating for 1 hour at 110° C. and cooled down very slowly. From these cylinders, flat discs or lenses were machined by conventional techniques. The lenses and discs were placed in hot distilled water for four hours to hydrate and extract solvents from them. Last, the lenses and discs were placed in isotonic saline for testing. The materials were optically clear, soft, tough and biologically compatible with eye tissue. Preliminary clinical testing of lenses was favorable. The discs have water contents of 83% and oxygen permeabilities of 59×10^{-11} cm³ cm/(sec cm² mmHg). The mechanical properties of the materials measured were:

PROPERTY	MEASURED VALUE
Young's modulus of elasticity	60 g/mm ²
Tensile Strength	97 g/mm ²
% Elongation	223
Tear Initiation	6.2 g/mm

EXAMPLE 4

Mixtures of 40 parts of 2-hydroxyethylmethacrylate, 60 parts of glyceryl methacrylate and X parts of 4-t-butylcyclohexyl methacrylate, 0.5 parts of ethylene glycoldimethacrylate and 0.5 parts of benzoin methyl ether, where X was 5, 7, and 10 parts, were made. Films were cast by placing the mixtures between glass plates as described in Example 1. After hydration, the films were not optically clear.

EXAMPLE 5

Example 4 was repeated except 4-t-butyl-2-hydroxycyclohexyl methacrylate was used in place of t-butylcyclohexyl methacrylate. The resultant films were transparent and tough. Up to 30 parts of the 4-t-butyl-2-hydroxycyclohexyl methacrylate was added to the mixture and the resultant films were optically clear. This demonstrates the solubilizing aspect of this strengthening monomer and shows that it can be used in higher concentrations than state of the art strengthening or strengthening agents.

COMPARATIVE EXAMPLE USING
t-BUTYLHYDROXYCYCLOHEXYL
METHACRYLATE AND
t-BUTYLCYCLOHEXYL METHACRYLATE

EXAMPLE 6

Films were made by the methods of Example 1 using the following compositions:

- (A) 2-Hydroxyethyl methacrylate (HEMA) 83.4 parts, n-methacryloylglycine (MG) 6 parts, ethyleneglycol-dimethacrylate (EGDMA) 0.6 parts, t-butylcyclohexyl-methacrylate (t-BCM) 10.0 parts, and benzoin methyl ether (BME) 0.17 parts by total weight;
- (B) HEMA 83.5 parts, MG 6.0 parts, 10 parts t-butylhydroxycyclohexyl methacrylate (TBE) and 0.5 parts EGDMA. To this mixture was added 0.17 parts by weight BME and 15 parts ethylene glycol as a diluent;
- (C) HEMA 73.5 parts, MG 6 parts, 20 parts TBE and 0.5 parts EGDMA. To this mixture was added 0.17 parts by weight of BME and 15 parts of ethylene glycol as a diluent; and
- (D) HEMA 63.5 parts, MG 6.0 parts, TBE 30 parts and 0.5 parts EGDMA. To this mixture was added 0.17 parts BME and 15 parts ethylene glycol.

The physical properties of the cast films were measured and are reported in Table 2.

TABLE 2

PROPERTY	FORMULATION			
	A	B	C	D
Young's modulus of elasticity g/m ²	142	44	97	5,860
Tensile strength g/m ²	65	40	49	293
% Elongation	75	166	113	95
Tear Initiation g/mm	51	25	78	66
% Water	56	65	58	49
Oxygen Permeability DK	16.2	34	27	16.2

The results show substantially more TBE can be added without affecting the oxygen permeability of the resulting polymer. The upper solubility limit for t-BCM was found to be about 15 parts before films were not optically clear on hydration. Although more TBE is required to obtain the same toughness as obtained by the strengthening agents of the present invention, this does not impact the oxygen permeability.

COMPARATIVE EXAMPLE USING
CYCLOHEXYLMETHACRYLATE,
t-BUTYLCYCLOHEXYL METHACRYLATE
AND TBE

EXAMPLE 7

A mixture was made using 84.7 parts of n-vinyl-2-pyrrolidinone, 15 parts of TBE and 0.3 parts of EGDMA. To this mixture was added 0.5 parts of 2,2-azobis(isobutyronitrile). The mixture was cast between glass

plates as described in Example 1. The samples were cured in an oven for 2 hours at 60° C., 1 hour at 80° C. and 1 hour at 100° C.. The film was released and boiled in distilled water for 4 hours, then put in a saline solution and tested. The properties of the film are reported below:

PROPERTY	MEASURED VALUE
Tangent modulus of elasticity	1100 g/mm ²
Tensile strength	220 g/mm ²
% Elongation	88
Initial Tear	19.9 g/mm
% Water	73.8
Oxygen Permeability	40

EXAMPLE 8

Example 7 was repeated except cyclohexyl methacrylate and t-butyl-cyclohexyl methacrylate were used to replace the TBE. The film was clear on casting, but immediately turned cloudy on hydration. That is, the material was not optically clear. This supports the conclusion that the novel monomer acts to toughen the material and to solubilize the components in the polymer.

Examples 1, 2, 3, 6, and 7 show that polymer compositions employing the strengthening agents of this invention are optically clear, possess high water contents, good oxygen permeability levels and good mechanical properties. The best results of this invention were obtained in Example 3, wherein the hydrophilic agent is N-vinyl-2-pyrrolidinone. The formulation of Example 3 provides a remarkably high water level and oxygen permeability while retaining unusually good mechanical properties. Based upon this data, the polymeric hydrogels of this invention can have water of hydration contents of 60, 70 or 80 weight percent, or more

Polymeric soft contact lens hydrogels of the prior art can achieve moderately elevated water of hydration levels while retaining good mechanical properties but can only achieve highly elevated water of hydration levels at the expense of good mechanical properties. For example, many such hydrogels with water of hydration levels of about 70 weight percent retain some mechanical properties. However, soft contact lens polymeric hydrogels of the prior art having water of hydration levels of 80 percent, or more, exhibit sharply reduced mechanical properties. In contrast to the prior art, the present invention is capable of producing polymeric soft contact lens hydrogels having water of hydration levels of 80, 82 or 85 weight percent, or more, while retaining good mechanical properties including Young's modulus of elasticity of at least 50 g/mm², generally; at least 75 g/mm², preferably; and at least 100 g/mm², most preferably; and an initial tear resistance of at least 2 g/mm, generally; at least 7 g/mm, preferably; and at least 10 g/mm, most preferably.

Table 1 shows the results of tests made with various formulations of N-vinyl-2-pyrrolidinone (NVP), 4-t-butyl, 2-hydroxycyclohexyl methacrylate (TBE) and ethylene glycol dimethacrylate (EDGMA) cross-linker. The formulations are given in weight percent.

TABLE 1

Monomer-Wt. Percent			Modulus of Elasticity g/mm ²	Tensile Strength g/mm ²	Elongation %
NVP	TBE	EGDMA			
84.642	15.058	0.299	1100	220	88.5
84.391	15.001	0.604	1530	214	65.0
84.103	14.993	0.900	1990	231	51.9
87.176	12.497	0.321	604	130	83.6
86.868	12.500	0.632	794	157	66.4
86.587	12.516	0.898	868	173	66.4
89.672	10.003	0.325	178	83.6	97.4
89.381	10.011	0.608	313	94.9	72.3
89.067	10.008	0.912	448	106.0	57.3
89.668	10.006	0.300	192	83.5	83.6
91.677	8.017	0.306	835	48.2	81.6
93.673	6.011	0.310	20.7	22.6	73.2
89.723	10.048	0.276	208	78.4	81.5
90.727	9.038	0.282	134	69.1	95.5
91.762	8.007	0.266	75.5	44.5	79.8
91.653	8.005	0.319	69	43.9	84.3
91.354	8.031	0.602	156	68.2	79.4
91.101	7.999	0.854	217	77.9	67.5
89.607	10.074	0.299	174	77.7	97.0
89.060	10.039	0.602	308	93.3	74.8
89.137	8.012	0.847	200	68.4	62.3
93.697	6.003	0.299	21.2	13.4	51.1
93.051	10.029	0.597	26.6	92.0	81.4
93.084	10.008	0.892	36.2	103.0	65.0

Table 2 shows the results of tests made to show water of hydration with various formulations of N-vinylpyrrolidinone (NVP), 4-t-butyl, 2-hydroxycyclohexyl methacrylate (TBE), and divinylethylene urea (DVEU). The results also show the amount of mono-

TABLE 2-continued

	WEIGHT PERCENT				WATER WT. %	EXTRACT WT. %
	NVP	TBE	DVEU	PLASTIZER		
5	70.5	14	0.5	15	76.7	6.7
	70.0	14	1.0	15	73.9	4.4
	82.5	11	1.5	5	71.5	-2.2
	86.0	8	1.0	5	77.4	-1.7
	81.5	8	0.5	10	81.9	2.9
	75.5	14	0.5	10	75.7	4.2
10	80.5	8	1.5	10	74.7	-3.3
	74.4	14	1.5	10	69.0	-1.7
	78.0	11	1.0	10	76.3	3.4
	80.5	14	0.5	5	76.4	9.2

Table 2 shows the high water of hydration levels achieved with the tested polymeric composition of this invention. All of the polymers showed hydration levels above 60 weight percent, most of the polymers showed hydration levels above 70 or 75 percent and some showed hydration levels above 80 percent. High levels of water of hydration are conducive to good oxygen permeability.

Table 3 shows the results of tests performed with two different polymer formulations of this invention. The first formulation was prepared from N-vinylpyrrolidinone (NVP), t-butyl 2-hydroxycyclohexyl methacrylate and divinylethylene urea (DVEU). The second formulation was prepared from N-vinyl-2-pyrrolidinone (NVP), t-butyl, 2-hydroxycyclohexyl methacrylate (TBE), divinylethylene urea (DVEU) and ethylene glycol dimethacrylate (EGDMA).

TABLE 3

Formulation	Modulus of Elasticity (g/mm ²)	Tensile Strength g/mm ²	Elongation %	Tear, Initial (g/mm)	Tear, Propagation (g/mm)	H ₂ O, Wgt. %
89.7/10/3	48.7	58.1	233.0	5.0	82.5	
86.7/13/3	117.0	89.5	220.0	7.7	80.2	
85.7/14/3	132.0	100.0	238.0	10.9	79.1	
83.7/16/3	218.0	124.0	217.0	15.9	79.5	
83.7/16/3	283.0	132.0	234.0	15.4	75.7	
NVP/TBE/DVEU/ EGDMA (Wgt. %)						
89.5/10/.25/.25		75.2	87.6	228.0	6.2	85.4
90/9/0/.3	129.0	97.0	111.0	5.9	82.7	

mer and oligomers extractable from the polymer.

TABLE 2

NVP	TBE	DVEU	PLASTIZER	WATER WT. %	EXTRACT WT. %
77.5	11	1.5	10	74.7	5.66
65.5	14	0.5	20	75.8	7.42
85.5	14	0.5	0	77.1	15.8
84.5	14	1.5	0	71.7	11.7
90.5	8	1.5	0	77.5	14.6
71.5	8	0.5	20	82.6	6.9
91.5	8	0.5	0	83.1	11.4
68.0	11	1.0	20	74.5	2.5
81.0	8	1.0	10	80.2	2.7
70.5	8	1.5	20	76.4	2.1
64.5	14	1.5	20	67.6	-0.4
85.0	14	1.0	0	73.9	6.1
88.5	11	0.5	0	80.0	12.1
86.7	13	0.3	0	80.1	11.9
71.0	8	1.0	20	79.0	0.08
65.0	14	1.0	20	72.3	2.7
75.5	14	0.5	10	76.3	4.4
86.7	13	0.3	0	79.7	14.5

Table 3 shows that the formulations of this invention which employ N-vinyl pyrrolidone as the hydrophilic monomer can achieve water levels of at least 85 weight percent. Formulations which employ t-butylhydroxycyclohexyl methacrylamide as the strengthening agent can achieve water levels above 79 weight percent. These high water levels are achieved while maintaining good mechanical properties.

EXAMPLE 9

The following three synthetic procedures describe the synthesis of two intermediates used to make TBE, and the TBE synthesis.

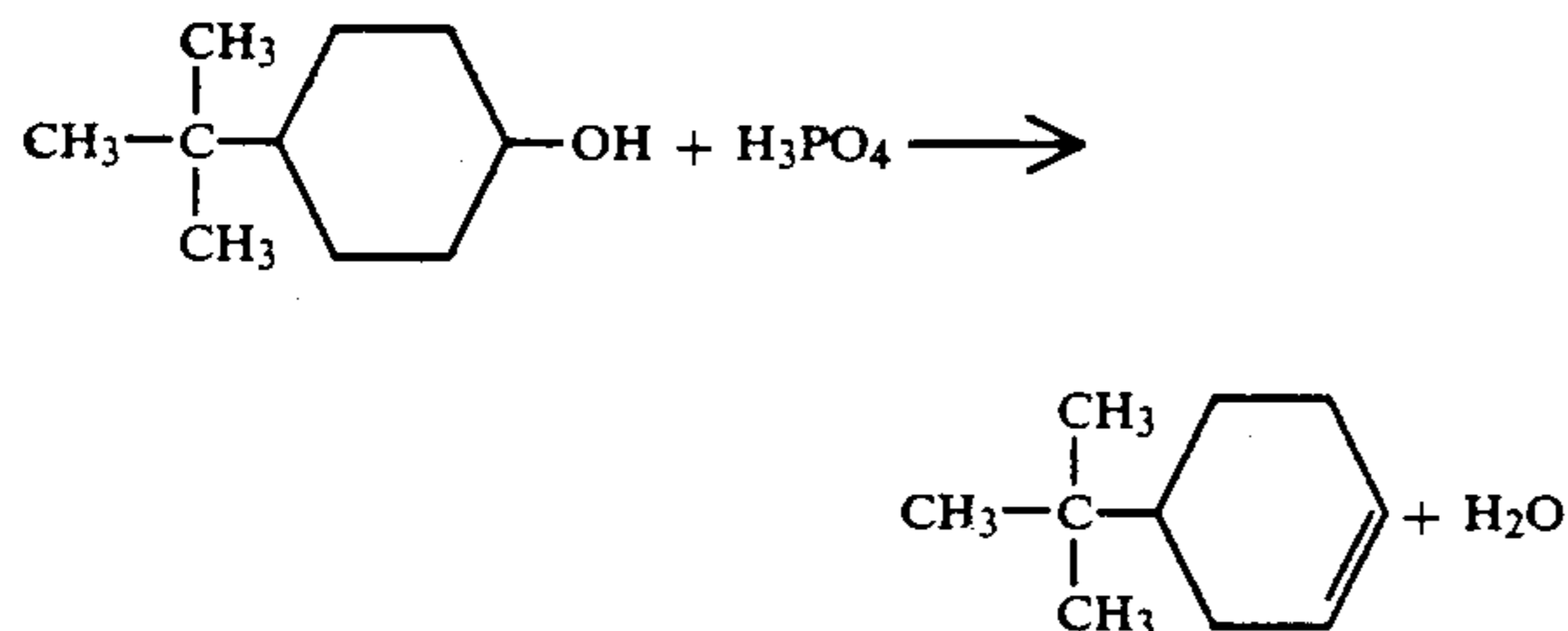
EXAMPLE 9A

Synthesis of 4-t-butylcyclohexene

4-t-butylcyclohexene, an intermediate in the synthesis of 4-t-butylhydroxycyclohexyl methacrylate, is prepared by reacting 4-t-butylcyclohexanol, a commercially

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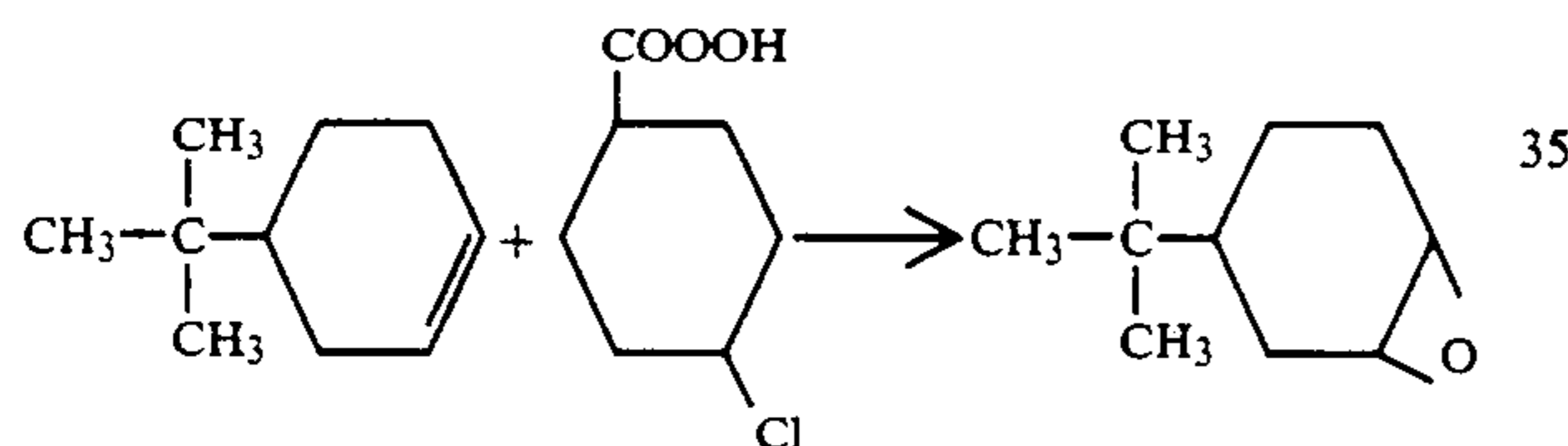
available material, with phosphoric acid. A mixture of 4-t-butylcyclohexanol and phosphoric acid is made by slow addition of the acid to the 4-t-butylcyclohexanol. This mixture is refluxed at about 70° C. until the reaction is complete. The reaction mixture is extracted with an organic solvent such as ethylacetate, dried over Mg SO₄ and filtered. The theoretical reaction is:



EXAMPLE 9B

Synthesis of 4-t-butyl-2-epoxycyclohexene

4-t-butyl-2-epoxycyclohexene, an intermediate in the synthesis of 4-t-butylhydroxycyclohexyl methacrylate, is prepared by reacting a 4-t-butylcyclohexene with m-chloroperoxybenzoic acid in ethylacetate below 5° C. until mixing is complete, and then at room temperature for two hours. The reaction mixture is washed with aqueous Na₂CO₃, dried over MgSO₄, and filtered. The theoretical reaction is:



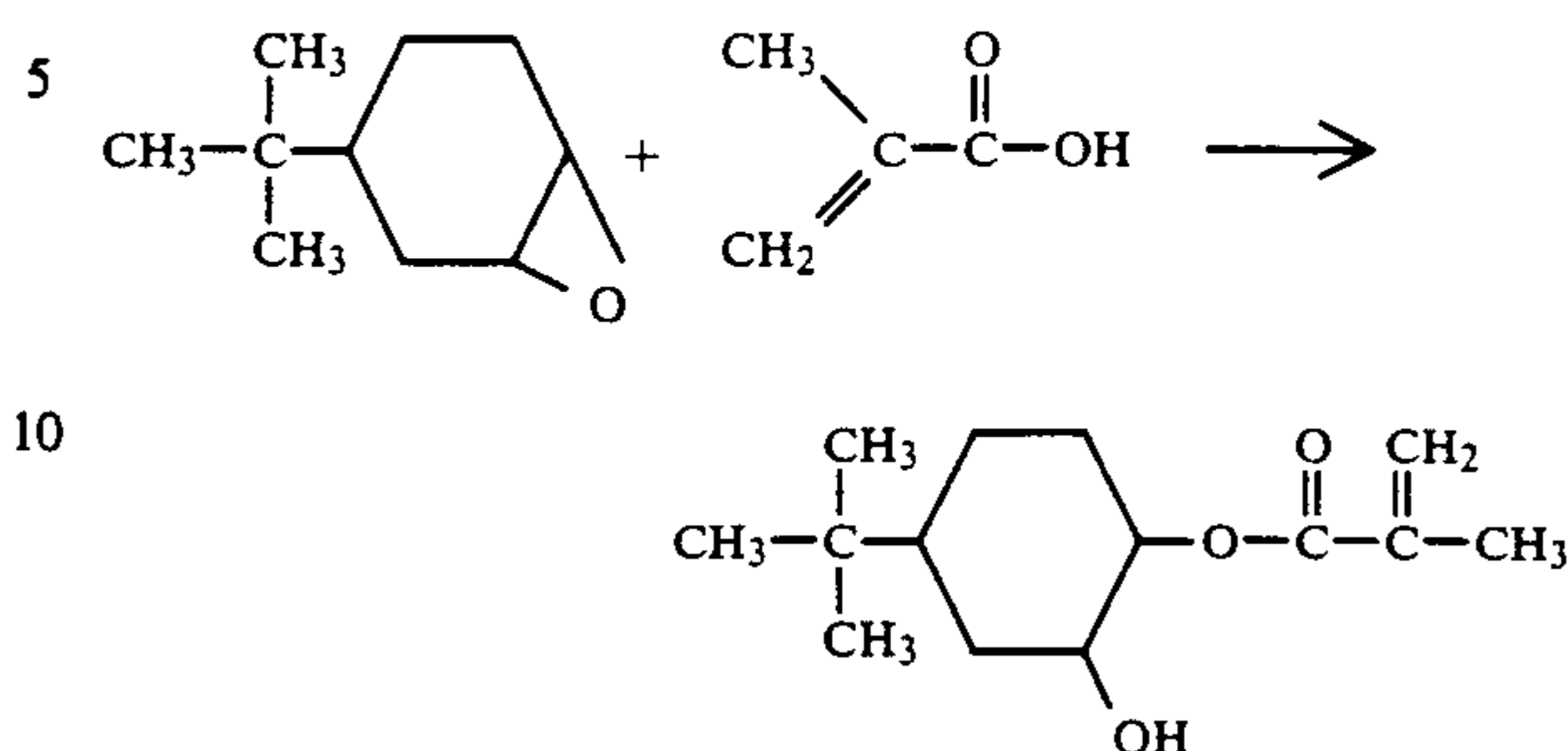
EXAMPLE 9C

Synthesis of 4-t-butyl-hydroxycyclohexyl methacrylate

4-t-butyl-2-epoxycyclohexene and methacrylic acid are reacted in the presence of CuCl, BHT and TEA for about 2 hours at about 90° C. Low boiling components

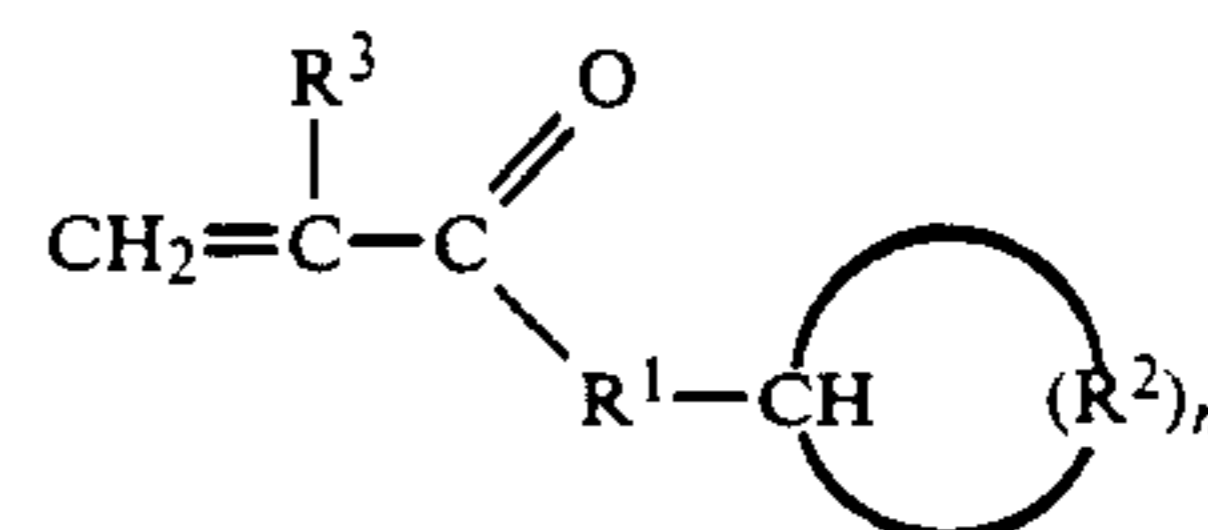
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are distilled off and the final product is purified by further distillation. The theoretical reaction is:



What is claimed is:

1. The polymerization product of a mixture comprising: 35 to 90 part by weight of N-vinylpyrrolidone; 0.1 to 5 parts by weight of crosslinking agent; 0.01 to 5 parts by weight of catalyst; and 10 to 65 parts by weight of a strengthening agent represented by the general formula



wherein:

R¹ is O or NH;

R² is a divalent alkylene radical chosen from the group consisting of —CH₂—, —CHOH— and —CHR⁴ wherein R⁴ is a branched alkyl group with 3 to 8 carbon atoms, and

R³ is H or CH₃;

and wherein at least one R² radical is —CHOH— and at least one R² is —CHR⁴ and are separated by at least one —CH₂— radical, and n is 4, 5, 6 or 7.

2. The polymerization product of claim 1 wherein said strengthening agent is 4-t-butyl, 2 hydroxycyclohexyl methacrylate.

3. The polymerization product of claim 1 wherein said strengthening agent is 4-t-butylhydroxycyclohexyl methacrylamide.

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